ORNL/CF-00/39

OAK RIDGE NATIONAL LABORATORY

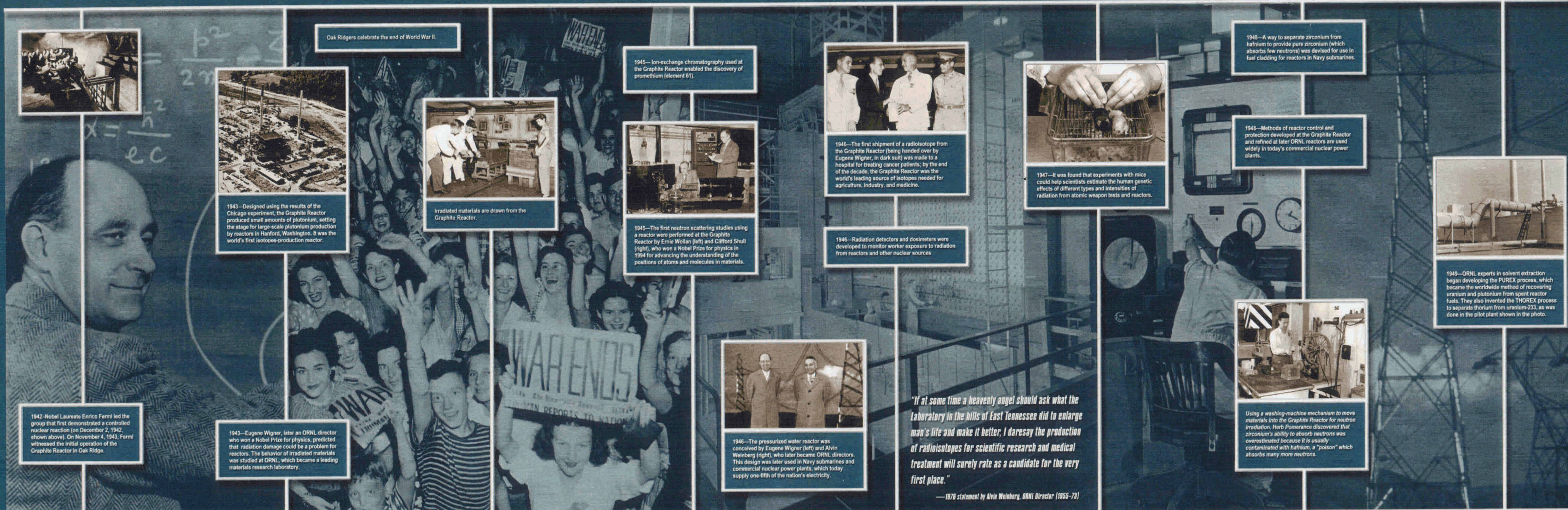
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

ornl

Home of the First Nuclear Reactor

In 1938 nuclear fission was discovered in Germany, and Albert Einstein wrote a letter in 1939 to President Franklin D. Roosevelt recommending that the U.S. develop an atomic weapon before the Germans did. Germany invaded Poland and World War II began. In December 1942 the first sustained and controlled nuclear chain reaction was demonstrated at the University of Chicago. The Manhattan Project was started to develop a U.S. atomic bomb. A site was selected in East Tennessee. In 1943 construction started on Oak Ridge National Laboratory (called Clinton Laboratories until 1948), including what became the world's first continuously operated nuclear reactor. Called the Graphite Reactor, it began operation November 4, 1943, and demonstrated that a reactor could produce plutonium in useful amounts. In 1945 World War II ended as the result of an atomic bomb using highly enriched uranium from Oak Ridge and another bomb using plutonium from three reactors at Hanford, Washington.

The farm community of Oak Ridge was selected as a site for Manhattan Project plants because of its isolation and access to rail lines, a river, and electrical power from the Tennessee Valley Authority.



1942–Nobel Laureate Enrico Fermi led the group that first demonstrated a controlled nuclear reaction (on December 2, 1942, shown above). On November 4, 1943, Fermi witnessed the initial operation of the Graphite Reactor in Oak Ridge.

1943—Designed using the results of the Chicago experiment, the Graphite Reactor produced small amounts of plutonium, setting the stage for large-scale plutonium production by reactors in Hanford, Washington. It was the world's first isotopes-production reactor.

1943—Eugene Wigner, later an ORNL director who won a Nobel Prize for physics, predicted that radiation damage could be a problem for reactors. The behavior of irradiated materials was studied at ORNL, which became a leading materials research laboratory.

Oak Ridgers celebrate the end of World War II.

Irradiated materials are drawn from the Graphite Reactor.

1945— Ion-exchange chromatography used at the Graphite Reactor enabled the discovery of promethium (element 61).

1945—The first neutron scattering studies using a reactor were performed at the Graphite Reactor by Ernie Wollan (left) and Clifford Shull (right), who won a Nobel Prize for physics in 1994 for advancing the understanding of the positions of atoms and molecules in materials.

1946—The first shipment of a radioisotope from the Graphite Reactor (being handed over by Eugene Wigner, in dark suit) was made to a hospital for treating cancer patients; by the end of the decade, the Graphite Reactor was the world's leading source of isotopes needed for agriculture, industry, and medicine.

1946—Radiation detectors and dosimeters were developed to monitor worker exposure to radiation from reactors and other nuclear sources

1946—The pressurized water reactor was conceived by Eugene Wigner (left) and Alvin Weinberg (right), who later became ORNL directors. This design was later used in Navy submarines and commercial nuclear power plants, which today supply one-fifth of the nation's electricity.

"If at some time a heavenly angel should ask what the Laboratory in the hills of East Tennessee did to enlarge man's life and make it better, I daresay the production of radioisotopes for scientific research and medical treatment will surely rate as a candidate for the very first place."

—1976 statement by Alvin Weinberg, ORNL Director (1955–73)

1947—It was found that experiments with mice could help scientists estimate the human genetic effects of different types and intensities of radiation from atomic weapon tests and reactors.

1948—A way to separate zirconium from hafnium to provide pure zirconium (which absorbs few neutrons) was devised for use in fuel cladding for reactors in Navy submarines.

1948—Methods of reactor control and protection developed at the Graphite Reactor and refined at later ORNL reactors are used widely in today's commercial nuclear power plants.

Using a washing-machine mechanism to move materials into the Graphite Reactor for neutron irradiation, Herb Pomerance discovered that zirconium's ability to absorb neutrons was overestimated because it is usually contaminated with hafnium, a "poison" which absorbs many more neutrons.

1949—ORNL experts in solvent extraction began developing the PUREX process, which became the worldwide method of recovering uranium and plutonium from spent reactor fuels. They also invented the THOREX process to separate thorium from uranium-233, as was done in the pilot plant shown in the photo.

1942 1943 1944 1945 1946 1947 1948 1949

Pioneers in Reactor Development and Radiation Protection

At a laboratory in its glory days for developing fission reactors as power sources, ORNL researchers examined a variety of ways of protecting the public from hazardous levels of radiation from reactors as well as nuclear tests. They designed shielding and radiation detectors, made recommendations based on animal studies that led to standards limiting human radiation exposures, studied the environmental effects of radioactive materials, and developed technologies to isolate radioactive waste from the environment. ORNL researchers also found ways to use radiation for studies of forests, materials, and genetic changes in mammals. ORNL produced radioisotopes and stable isotopes for medical diagnosis and treatment. And ORNL conducted experiments to support the goal of producing controlled nuclear fusion energy for power generation.

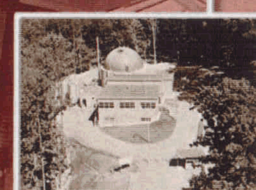
Leo Holland, an Oak Ridge reactor expert, describes the 1955 Geneva Conference reactor (built at ORNL) to President Dwight Eisenhower.

1950 — Reactor-produced radioactive materials were first used at ORNL to trace the natural movement of nutrients and pollutants in forests.

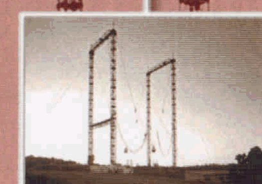
1951 — ORNL's Bulk Shielding Reactor provided data for calculations to determine how best to make shielding—different thicknesses and configurations of lead, steel, and concrete—adequately protect people and equipment from exposure to hazardous radiation levels.

1952 — ORNL researchers Liane and Bill Russell informed the medical community that the stage of prenatal development in mice strongly influences the amount and type of radiation damage to the embryo and fetus. Their specific recommendations for avoiding the risks of diagnostic X rays to unsuspected human pregnancies were adopted worldwide.

1953 — ORNL's Oak Ridge Automated Computer and Logical Engine (ORACLE), then the world's most powerful computer, was slower and less powerful than today's desktop machines.

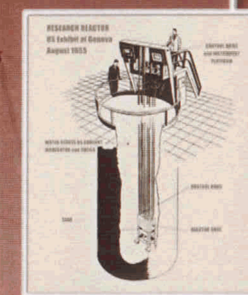


1953 — For the U.S. Army, ORNL designed a transportable reactor to generate heat and electricity at remote sites such as Antarctica, Greenland, and the Panama Canal Zone. Above is an aerial view of the Army Package Reactor building at Fort Belvoir, Virginia.



1954 — The Tower Shielding Facility provided data for ORNL calculations to aid the design of compact, lightweight shielding to protect a nuclear airplane's flight crew from reactor radiation. The nuclear-powered plane was never built, but ORNL's participation in the national Aircraft Nuclear Propulsion Program produced a wealth of useful nuclear technologies.

1954 — The first successful experiment was carried out in which a chemical reaction was studied by colliding molecular beams of two different reactants.



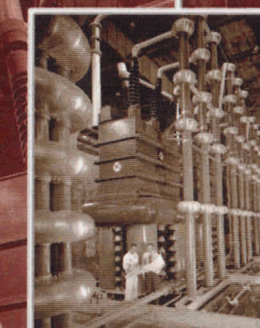
1955 — ORNL's most famous reactor of the 1950s (shown in drawing) was the small "swimming pool" reactor shipped to Geneva, Switzerland, for the first United Nations Conference on Peaceful Uses of the Atom.

1956 — Using ORNL mouse data, a National Academy of Sciences committee predicted genetic effects of radiation in humans. Later, national and international bodies relied on ORNL data for recommending human radiation exposure limits.

1956 — Neutron dosimetry techniques that have been used throughout the world were devised to protect workers from exposure to hazardous levels of radiation.

1956 — ORNL biologists used radiation to suppress the immune response in mice and then performed the world's first bone marrow transplants.

1956 — Using radioactive tags to study the chemistry of life, ORNL biologists discovered that messenger RNA "reads" DNA's genetic code and turns itself into a template for mass-producing proteins.



1957 — ORNL's first fusion research device, the Direct-Current Experiment (DCX), showed that hydrogen ions could be obtained and trapped in a magnetic field.

1957 — ORNL provided leadership in setting standards on permissible doses of radiation for medical diagnosis and treatment and for the workplace.

1958—Spreading a certain dose of radiation dose over weeks was found to produce fewer mutations in mice than giving the same amount within minutes. This work provided the first evidence that damage that results in mutations can be repaired.

1958 — Performing the first experiment on the Oak Ridge Research Reactor, researchers confirmed the electron-neutrino theory of beta decay. For 30 years, the ORR was used to produce radioisotopes for industrial and medical uses, study the effects of radiation on materials, and carry out neutron scattering experiments that uncovered the rich variety of crystal and magnetic structures in rare-earth elements. In above photograph, ORNL Director Alvin Weinberg (second from right) shows the ORR control room to then Senator John F. Kennedy, Senator Albert Gore, Sr., and Jacqueline Kennedy.

1958 — ORNL began "Project Salt Vault," the first national effort to site a high-level nuclear waste repository. Pictured is an interior of a salt mine near Lyons, Kansas, an ORNL test site for storing nuclear wastes.

1959 — Maleness in the mouse was found to depend on the presence of a Y chromosome.

1959 — The Clinch River was studied to evaluate the potential long-term hazards of radioisotope releases from a major nuclear facility.

1950 | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959

Advancing Reactor and Computer Technologies

ORNL achieved international recognition for its promotion of nuclear-powered "Water for Peace" desalination plants for "making the desert bloom." Its other reactor successes included the operation of the Molten Salt Reactor Experiment and the startup of the High Flux Isotope Reactor, which is still used today for radioisotope production and neutron-scattering experiments. Using computer modeling and other approaches, ORNL researchers helped launch the electronic revolution. They developed computer codes to better understand changes in forests, analyze operational problems in reactors, assess the effectiveness of shields and fallout shelters in protecting people and equipment from radiation, and predict whether conditions could lead to a radiation-releasing criticality accident. Because of public concerns about the increasing presence of reactors, nuclear safety became a growing field at ORNL.

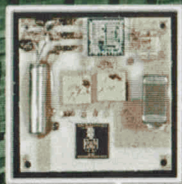
President Lyndon B. Johnson (left), Senator Al Gore Sr., and Sam Sapirie, manager of the Oak Ridge Operations of the Atomic Energy Commission, view the Oak Ridge Research Reactor.

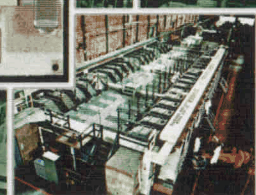
1960

1960—Personal radiation monitors were developed, including the pocket screamer that chirps and flashes when gamma radiation levels go too high.

1960—A program was started to develop graphite structures and coated-particle fuels for high-temperature gas-cooled reactors.

1961





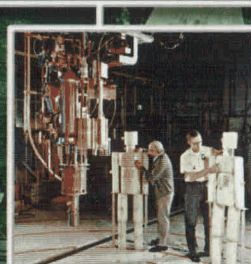
1961—Integrated circuits for electronic applications were first developed as a result of ORNL's calutrons (normally used to produce stable isotopes). They were used to show that silicon implanted with boron and phosphorus ions forms electrical junctions and then to produce semiconductor samples for industry.

1961—ORNL researchers developed advanced mathematical and computer approaches to understanding the dynamics of terrestrial ecosystems.

1962

1962—A forest stand in Oak Ridge was tagged with cesium-137, providing data for computer models and validating the long-term behavior of this key radioactive waste material.

1962—Aided by computer modeling, ORNL physicists discovered ion channeling in crystalline solids. This insight that energetic ions aimed down open regions in crystal lattices lose less energy than those ions entering in random directions led to precisely controlled implantation of electrically active impurities within crystals. The result: improved semiconductor chips that created the electronic revolution.



1962—The Health Physics Research Reactor provided radiation-exposure data that helped scientists refine occupational dose limits, design dosimeters for nuclear workers, and devise shields for power plants and space craft.

1962—ORNL became a center for research on civil defense to protect the U.S. population in case of a nuclear war. Drawing on its expertise in shielding and radiation protection, the center evaluated protective measures such as underground shelters.

1963

1963—The Radiation Shielding Information Center at ORNL implemented concepts for information analysis centers in specialized fields, as suggested by a Presidential panel led by ORNL Director Alvin Weinberg.

1963—ORNL researchers applied analysis of signal fluctuations (noise) to the identification of operational problems in some reactors, such as vibrations in key parts caused by coolant water flow. ORNL measurements later prompted the decision to let some commercial reactors operate at reduced power until the problem was solved.

1963—The Oak Ridge Isochronous Cyclotron (ORIC) was first operated. It later played an important role in the Holifield nuclear physics accelerator complex

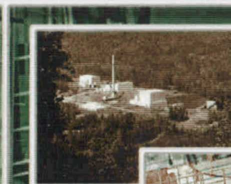
1964

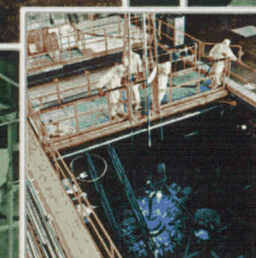
1964—ORNL's "Water for Peace" desalination concept in which heat from nuclear reactors in arid lands produces irrigation water for agriculture from seawater was featured at a United Nations conference. Nuclear-powered desalination complexes were planned for India, Israel, Mexico, Puerto Rico, and the Soviet Union. Pictured are Congressman Gerald Ford (left) and then ORNL Director Alvin Weinberg.

1965

1965—Drawing on methods used to study radiation effects on mice, a long-range program was started to measure the genetic effects of chemicals such as pesticides, gasoline fumes, drugs, and tobacco.

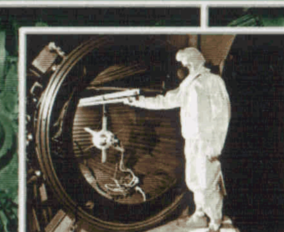
1966





1966—ORNL's High Flux Isotope Reactor, which has the world's highest steady-state thermal neutron flux, continues to be used for neutron scattering experiments, materials irradiation, neutron activation analysis, and production of transuranium isotopes, such as californium-252, which is used to treat cancer.

1966—The discovery of delayed light was one of ORNL's internationally recognized fundamental discoveries in photosynthesis, including evidence for the electronic nature of the process's first step.



1966—An important achievement of a program to develop radioisotope heat sources to power space satellites was the construction of an isotope-powered generator (shown above) for the lunar probe Surveyor.

1967

1967—ORNL's Heavy-Section Steel Technology Program overpressurized intermediate reactor vessels until they fractured. Typically, three times the design pressure was required to induce failure or leakage, confirming that standard reactor operating pressures are safe. Pictured above is Tom Hill.

1967—A long-running program was started to evaluate the effects of flaws, property variations, and residual stresses on the reliability of pressure vessels in light-water reactors.

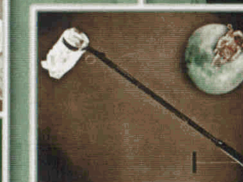
1967—Studies of the effects of pollutants and movements of nutrients in living systems in water and on land began at the new Walker Branch Watershed research facility. The National Science Foundation selects ORNL to lead a major study of ecosystems in the eastern United States.

1968

1968—Developed by Norman Anderson and his associates, ORNL's centrifugal fast analyzer was made into a commercial product that revolutionized medical testing of body fluids in hospitals and clinics.

1968—ORNL's Molten Salt Reactor Experiment, which was the first reactor to operate on uranium-233 fuel, was brought to power with the aid of Nobel Laureate Glenn Seaborg, shown above.

1969



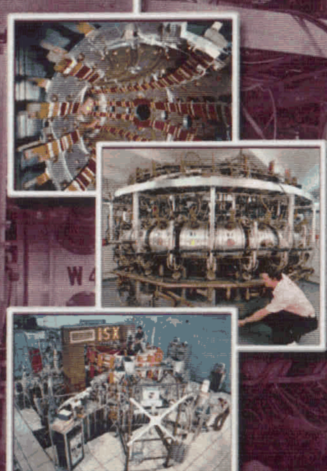
1969—The Apollo 11 moon rock scoop was designed at ORNL.

An Energy and Environmental Laboratory Blossoms

After the Mideast oil embargo of 1973–74, the U.S. government sought to diversify its energy sources and decrease U.S. dependence on imported oil. In response to the environmental movement, Congress passed new environmental laws. Originally a nuclear research lab, ORNL evolved into a laboratory that developed non-nuclear as well as nuclear energy sources. These non-nuclear energy sources included coal and fusion. Technologies for conserving energy were also being developed. ORNL researchers evaluated the health and environmental risks of various energy sources.

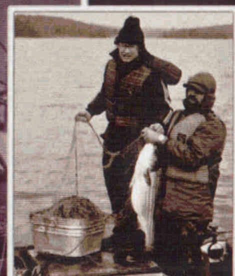
In 1978 President Jimmy Carter and Secretary of Energy James Schlesinger participated in a discussion at ORNL.

1970



1970—ORNL researchers conducted tests on its new doughnut-shaped (tokamak) fusion research machine, the ORMAK. During the 1970s researchers also built and tested the ELMO Bumpy Torus and devices called Impurity Study Experiments to illuminate the behavior of impurities inside fusion reactor plasmas.

1971



1971—To help AEC prepare required environmental impact statements for nuclear power plants, ORNL reseearchers gathered needed data on the impacts on fish of heated cooling water from these facilities. This research led to strict temperature limits on nuclear plant discharges, resulting in the installation of massive cooling towers. Pictured above are Chuck Coutant (left) and a Tennessee Technological University researcher catching striped bass in Watts Bar Lake for fish tagging studies.

1971—Nuclear safety research studies determined at what reactor temperatures and pressures the cladding of nuclear fuel rods begins to collapse.

1972

1972—A set of stiffer nuclear safety criteria emerged after ORNL scientists testified along with nuclear-power opponents at AEC's public hearings on emergency cooling of reactor cores.

1972—Researchers at ORNL froze, thawed, and implanted mouse embryos in surrogate mothers, who gave birth to healthy mouse pups. The technique was adopted by the livestock industry for multiplying the reproductive potential of prize cattle.

1972—ORNL researchers began a program of energy conservation research, which later resulted in national insulation standards, more efficient delivery of electrical power, and more energy-efficient designs for refrigerators, heat pumps, ovens, and water heaters.

1973

1973—ORNL scientists analyzed moon rocks for uranium and thorium.

1974

1974—The Energy Reorganization Act created the Energy Research and Development Administration (ERDA) and the U.S. Nuclear Regulatory Commission (NRC) from the Atomic Energy Commission. Four years later, ERDA became the Department of Energy (DOE), the major source of funding to ORNL and other national labs.

1974—A chromium-molybdenum steel was developed at ORNL for the U.S. government's breeder reactor project. It is now manufactured and marketed internationally for use in electric utility boilers and oil refinery furnaces.

1975

1975—Because of disruptions in the supply of Mideastern oil to the U.S., the government started research on producing liquid and gaseous fuels from coal. Pictured above is Richard Forrester, who is measuring heat transfer in coal blocks for coal gasification studies.

1975—Wes Shumate (in background) injects a culture of bacteria into an experimental bioreactor. Bioreactors were developed to produce chemicals and fuels (e.g. ethanol from corn) and treat waste streams.

1975—Some 40 to 70% of sulfur and nitric acids deposited on ORNL's Walker Branch Watershed forest was found to have arrived in dry particulates rather than rain.

1975—A tougher iridium alloy was created to contain plutonium fuel for radioisotope thermoelectric generators that power the Voyager I, Voyager II, Galileo, Ulysses, and Cassini spacecraft.

1976

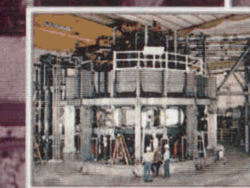
Henry Wilson studies the composition and mobility of trace contaminants found in the residues from various coal conversion processes.

Barbara Walton examines an abnormal cricket grown from an egg that had been exposed to coal-derived chemicals.

1976—Biological effects of chemicals produced by converting coal to liquid and gaseous fuels were studied. This work led to ORNL developing the scientific field of ecological risk assessment, including a risk assessment method adopted by the U.S. Environmental Protection Agency.

1977

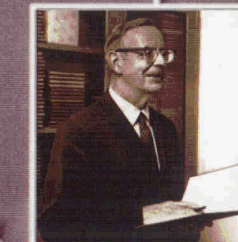
1978



1978—ORNL researchers developed a method for refueling fusion reactors by injecting frozen hydrogen pellets into their plasmas. The pellet injector (used at the Princeton Plasma Physics Laboratory's Tokamak Fusion Test Reactor, pictured above) was later adopted for tokamaks in Europe and the U.S. A year later, ORNL's neutral-beam injectors achieved record fusion plasma temperatures at the PPPL.

1978—The small angle X-rayscattering device became part of a National Center for Small-Angle Scattering Research established at ORNL.

1979

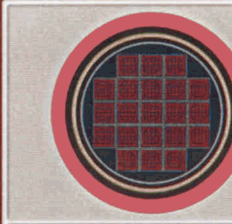


1979—Bill Russell, a renowned ORNL geneticist, discovered that ethylnitrosourea is the most effective chemical in inducing mutations in mice. ENU is now used widely to discover genes linked to human diseases.

1979—ORNL researchers helped determine the cause of the loss-of-coolant accident at the Three Mile Island nuclear power plant. They also assessed the core damage, helped prevent the release of radioactively contaminated gases, and devised ways to decontaminate thousands of gallons of emergency coolant.

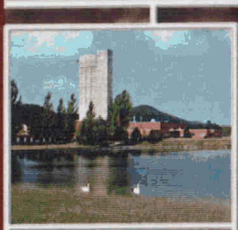
A Materials Lab That Matters

In the 1980s, ORNL opened new "user" facilities to let outside scientists join ORNL researchers in probing the nature of matter, developing improved materials (especially for transportation vehicles), and studying ways to extract more energy from matter. The new materials developed at the Laboratory include ion-implanted alloys for knee and hip replacements, ductile nickel aluminides for industrial uses, and whisker-toughened ceramics for commercial cutting tools. Researchers also devised ways to form tough, heat-resistant ceramics and shape these materials into automotive turbines. ORNL researchers became more involved in transferring the benefits of their work through licenses of their patented technologies and cooperative research and development agreements with private companies.



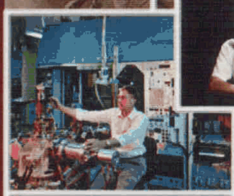
This model of a transport cask loaded with spent nuclear reactor fuel is a visualization of the ORNL-developed Standardized Computer Analysis for Licensing Evaluation (SCALE) code used worldwide to ensure that stored or transported fuel will not release a hazardous amount of energy and radiation.

1980



1980—The Holifield Heavy Ion Research Facility began operation for nuclear physics studies and became a scientific user facility. The 25-million-volt electrostatic accelerator, which was linked to the Oak Ridge Isochronous Cyclotron, had the highest direct-voltage current in the world.

1980—The 12,400 acres of the new National Environmental Research Park at ORNL offered a living laboratory for studies of acid rain, animal populations, pollutant migration through forests, and waste-digesting bacteria.



1980—Bill Appleton (above), Jim Williams (right), and others developed accelerator-based ion implantation techniques to improve the properties of semiconductors, metallic alloys, and ceramics. It was discovered that implanting the surface of an artificial titanium-alloy knee or hip with nitrogen ions greatly improves its resistance to wear and corrosion, delaying the need for a painful replacement operation.

1981

1981—Work was begun to make brittle nickel aluminides ductile; ORNL's modified aluminide alloys have been used in industrial heat-treating equipment, rolls for making steel, and dies for making truck brake parts. Pictured above are modified nickel aluminide furnace trays that hold automobile parts transferred to a furnace for heat treating at General Motors–Saginaw.

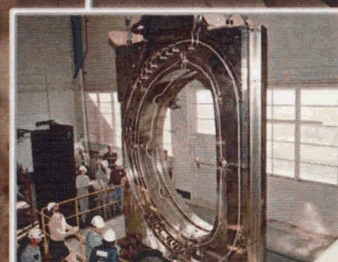
An assortment of parts, including tubing and ceramic heat-engine components as well as cutting tools, can be made from ORNL's fracture-resistant whisker-reinforced ceramics.

1981—ORNL researchers began developing whisker-toughened ceramics now used to make commercial cutting tools.

1982

Bob DeVault designed the gas-fired triple effect absorption chiller for cooling commercial buildings.

1982—ORNL developed insulation standards adopted later by federal agencies and standards to make electric appliances more efficient. ORNL designs led to more efficient commercial heat-pump water heaters and refrigerators.



1982—At ORNL's Large Coil Test Facility, researchers from several nations successfully tested superconducting electromagnets half the size of those expected to be used at future fusion power plants.

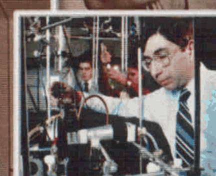
1982—The Carbon Dioxide Information Analysis Center, which was established at ORNL to serve DOE's Carbon Dioxide Research Program, later became an internationally known repository of data on global change. CDIAC is one of the best known of ORNL's information centers, which started with the nuclear data center in the 1940s. Information centers for collecting, analyzing, and synthesizing information proliferated at ORNL in the 1960s and 1970s. They embrace such areas as nuclear safety, toxic materials, and the human genome.

1982—ORNL initiated an extensive ten-year study for the Nuclear Regulatory Commission of fission product release (species and rates) from heated nuclear reactor fuel. Results from this work continue to be referenced as the best available information concerning potential release under accident conditions.

1983

1983—Hypercube concurrent computers were first operated at ORNL's Center for Engineering Science Advanced Research to control robots. Above, Bill Hamel (left) and Chuck Weisbin, then CESAR director, examine the HERMIES-II robot then used by CESAR for concept demonstrations of artificial intelligence planning and learning algorithms.

1984



1984—Eli Greenbaum (above) studied photosynthetic water splitting using spinach and later algae for releasing energy-rich gases, such as hydrogen.

1985

1985—ORNL researchers developed gelcasting, an advanced process for forming ceramic material into complex shapes such as automotive turbines, accelerator magnets, and artificial bone.

1985—At the HHIRF physicists discovered the giant quadruple resonance in nuclei bombarded with highly energetic ions. In this phenomenon, the nucleus alternately compresses and expands, causing many of its protons and neutrons to move at the same time.

1985—ORNL's first distributed memory parallel computer was delivered. This Intel iPSC/1, which had 32 central processing units, was a predecessor of the Intel Paragon supercomputer (shown above), which was installed at ORNL in 1992.

1986

1986—The High Temperature Materials Laboratory was completed, enabling research on developing ceramics for the most energy-efficient engines and high-temperature superconducting materials for efficient electricity distribution.

1986—ORNL developers published the three-dimensional TORT radiation transport simulation code.

1987

1987—The High Temperature Materials Laboratory opened as a user facility. Guest researchers from industry, academia, and other government laboratories used HTML's suite of sophisticated instruments to characterize their materials and determine how to improve them.

1987—In research on the newly discovered phenomenon of high-temperature superconductivity, ORNL researchers were among the first to use laser ablation to make superconducting thin films.

1988

1988—The Advanced Toroidal Facility began operating, allowing ORNL researchers to learn more about the physics of fusion energy from experiments on this stellarator.

1989

1989—ORNL began work with the Nuclear Regulatory Commission to develop the Generic Environmental Impact Statement for use in renewing the licenses of more than 100 U.S. commercial nuclear power plants.

1989—ORNL's Center for Global Environmental Studies was formed. ORNL is a leader in studies of the environmental effects of increased atmospheric concentrations of carbon dioxide. Pictured above is Mike Farrell.

ORNL: A Partner in Solving Scientific Problems

ORNL is the largest of the U.S. Department of Energy's five multipurpose, nonweapons laboratories. We conduct research to help the federal government provide leadership in key scientific areas, increase the availability of clean abundant energy, restore and protect the environment, preserve national security, and strengthen national economic competitiveness. We have 17 national DOE user facilities for researchers around the country. In a partnership with five other DOE laboratories, we are building a major scientific research facility, called the Spallation Neutron Source, which will enable better understanding of physical and biological materials, ranging from polymers to proteins. We also have a collection of 60,000 mice that are helping us further our success in finding better ways to diagnose and treat disease.

President George Bush (center) spoke at ORNL in 1992. Here he witnesses the signing of an ORNL-industry agreement on ceramics research. From left are Secretary of Energy James Watkins, Coors President Joseph Coors, Jr., shaking hands with ORNL Director Alvin Trivelpiece, and Secretary of Education Lamar Alexander.

1999—Vice President Al Gore was keynote speaker when ground was broken Dec. 15, 1999, for the Spallation Neutron Source, which is expected to be built by 2006 by a partnership involving ORNL and five other DOE national labs. The SNS will be the world's most powerful pulsed source of neutrons.

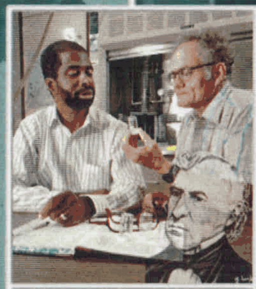
1990

1990—Z-contrast imaging, developed at ORNL, allowed scientists using a scanning transmission electron microscope to see columns of atoms in materials ranging from superconductors to automobile catalysts.

1990—Scientists used the Oak Ridge Electron Linear Accelerator to confirm the existence of separate positive and negative electrical charges (quarks) within the neutron. ORELA was later used to help shed light on the synthesis of elements in the universe.

1990—The Airlift Deployment Analysis System (ADANS) computer code developed at ORNL was used to efficiently deploy military personnel and equipment to the Persian Gulf, Somalia, Rwanda, Haiti, and Bosnia.

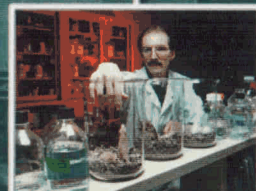
1991



1991—Neutron activation analysis using reactors, which was pioneered at ORNL and used for forensic studies, was applied to hair and nail samples from the grave of President Zachary Taylor. Results of the analysis at ORNL's High Flux Isotope Reactor indicated he had not been poisoned by arsenic while in office, as one historian suspected. Pictured are Larry Robinson (left) and Frank Dyer.

1991—Researchers at ORNL and the University of Tennessee developed a parallel virtual machine (PVM) software package that allows desktop computers linked by a network to be used as a single large parallel computer. It is being used worldwide to solve important scientific, industrial, and medical problems.

1992



1992—ORNL researchers (including Ed Michaud, shown above watching the activity of normal and mutant mice in large beakers) identified and cloned the mouse agouti gene, which causes altered fur color, obesity, diabetes, and skin cancer in mice and which has a human counterpart.

1992—ORNL researchers developed a neural-network system for recognizing genes in DNA sequences sent to it by electronic mail. The Gene Recognition and Analysis Internet Link (GRAIL) system is widely used today.

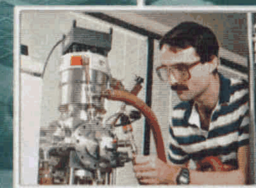
1993

1993—The rhenium-188 isotope generator was developed to treat cancer-induced bone pain and arthritis and prevent the buildup of smooth muscle cells in coronary arteries after balloon angioplasty. Since the mid-1970s, using radioisotopes from Laboratory sources, ORNL's nuclear medicine researchers developed new radioactive imaging agents for medical scanning diagnosis of heart disease. Above, a patient's heart is imaged using ORNL's iridium-191*m* generator system (*courtesy of Cyclotron Research Center, University of Liege, Belgium*).

1993—ORNL's Tuan Vo-Dinh (left) and two medical researchers at Thompson Cancer Survival Center of Knoxville developed a new laser technique for determining without surgery whether a tumor in the esophagus is cancerous.

1994

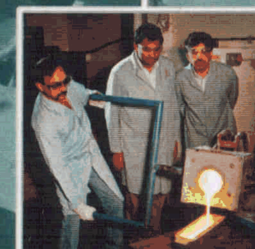
1994—ORNL researchers led by Mike Ramsey (above) developed the "lab on a chip," which shows promise as a fast and inexpensive method for DNA sequencing and forensic fingerprinting, environmental monitoring, diagnosing disease, and developing new drugs.



1994—ORNL researchers (including Scott McLuckey, shown above operating a mass spectrometer) developed mass spectrometry techniques for detecting or analyzing explosives, engine exhaust, carriers of the cystic fibrosis gene, and proteins. A direct-sampling ion trap mass spectrometer devised to detect environmental pollutants will be used to detect biological and chemical warfare agents.

1995

1995—ORNL researchers developed the rolling-assisted biaxial textured substrates (RABiTS™) technique for fabricating nickel-based, high-temperature superconducting wire. Above, Mariappan Paranthaman uses electron beam evaporation to make a superconducting wire 7 centimeters long.

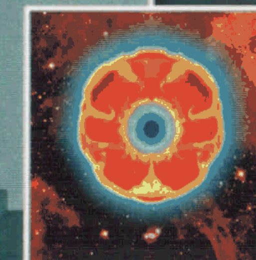


1995—ORNL researchers led by Vinod Sikka (right) developed a technique for efficiently and safely melting and casting alloys of ORNL-designed nickel aluminides, which are used by the automobile and steel industries.

1996

1996—ORNL researchers (including Ed Vineyard, shown above examining an instrumented refrigerator) developed a more energy-efficient refrigerator-freezer by altering a popular refrigerator model to cut its energy use in half.

1997



1997—At the Holifield Radioactive Ion Beam Facility, nuclear structure and nuclear astrophysics studies began, using radioactive ions that do not exist naturally on the earth. A radioactive fluorine beam was developed to measure the rates of nuclear reactions that produce isotopes in stars. ORNL supercomputers are used to model forces within exploding stars (supernovae) that disseminate elements essential to life on the earth (see image above).

1997—Lynn Parker developed ALLIANCE which directs teams of robots like these in carrying out tasks cooperatively.

1998

1999—An upgrade of the High Flux Isotope Reactor will allow it to lead the world in both thermal and cold neutron intensities for use in neutron science. Neutron scattering experiments at HFIR and elsewhere have contributed information that has led to improved consumer products, such as credit cards, computer disks, compact discs, automatic windows, shatterproof windshields, and life-saving bulletproof vests.

1998—Rich Norby on the hydraulic lift collects tree leaves as part of a large-scale ORNL ecological experiment to determine the effects on forest growth of increased concentrations of atmospheric carbon dioxide and reduced precipitation.

1999

1999—Some of ORNL's 60,000 mice are now being scanned with the MicroCAT, a high-resolution X-ray imaging device developed to detect noninvasively internal genetic disorders in mammals whose parents were exposed to radiation or chemicals. Shown above are Kevin Behel (left) and Mike Paulus.

1999—Xudong Fang uses Z-contrast transmission scanning electron microscope to study iodine-doped carbon nanotubes, strong materials that conduct electricity.

Inset: The world's sharpest electron microscope image of a crystal was recorded in 1998 at ORNL. This image of a silicon crystal had double (0.78 vs. 1.6 Angstrom) the resolution of a typical transmission electron microscope image.